IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

REQUEST FOR FILING
(RULE 53(b)(1))

For Design or Utility Applications

(DO NOT USE FOR CIPs)

~~Rule~~ 53(b)(1) PATENT APPLICATION:

☒ Continuation)
) application under 37 CFR 1.53(b)(1)
☐ Divisional)
application under 37 CFR 1.53(b)(1)
of pending prior application of

Group Art Unit: 2815

Examiner: J. JACKSON

Inventor(s): KOIDE et al.

Parent Appln. No.: 08 (Series Code ⇧) | 925,323 (Serial No. ⇧)

Atty. Dkt. PM 268415 (New M#) | T36-127889 M/KOH (Client Ref)

Parent Filed: September 8, 1997

This Appln. Filed: November 15, 2000

Title: METHODS FOR MANUFACTURING A LIGHT-EMITTING DEVICE (as amended)

Hon. Commissioner of Patents
Washington, DC 20231

Date: November 15, 2000
(Parent Matter No. 241197)

Sir:

To effect the above-requested filing today:

1. **Attached** is a copy **(which must be filed)** of the prior application, including:

☒ Abstract
☒ Specification and claims (17 pages) **(must be attached)**
☒ Drawings **(must be attached if originally filed):** 2 sheet(s)/set: ☒ 1 set informal; ☒ Formal of size ☒ A4 ☐ 11"

1A. Always X one box, only:
(1) ☒ Copy of Signed declaration or oath as originally filed in prior application attached
(2) ☐ NO declaration or fee is enclosed; therefore, this is a filing under Rule 53(f).

2. ☐ This application is hereby filed by less than all of the inventors named in the prior application. Petition is hereby made requesting deletion as inventor(s) of the following who is/are **not** inventor(s) of the invention being claimed in this application (DELETE THE FOLLOWING INVENTOR(S)):

1. ______ 2. ______
3. ______ 4. ______
5. ______ 6. ______
7. ______ 8. ______

2.5 THE INVENTOR(S) FOR THIS NEW APPLICATION IS(ARE):

1. Norikatsu KOIDE
2. Masayoshi KOIKE
3. Shiro YAMASAKI
4. Isamu AKASAKI
5. Hiroshi AMANO
6. ______
7. ______
8. ______

3. The entire disclosure of the prior application is considered as being part of the disclosure of the accompanying application and is hereby incorporated therein by reference thereto.

4. ☒ Priority is claimed under 35 U.S.C. 119/365 based on filing in Japan (country) of

	Application No.	Filing Date		Application No.	Filing Date
(1)	8-257818	September 8, 1996	(2)		
(3)			(4)		
(5)			(6)		

a. ☐ ______ (No.) Certified copy/copies attached.

b. ☒ Certified copy/copies previously filed on March 20, 1998 in U.S. Application No. 08/925,323, filed on September 8, 1997.
series code ⇧ ⇧ serial no.

c. ☐ Certified copy/copies filed during International stage of PCT/ / . filed .

4. (a) ☐ Domestic priority is claimed from ___/___ , PCT/

(b) ☐ Benefit is claimed of Provisional Application No. 60/___ , filed ___ .

5. ☒ Prior application is assigned to 1)TOYODA GOSEI CO., LTD.; 2)Isamu Akasaki and 3)Hiroshi Amano

by assignment recorded March 20, 1998 (Date) Reel 9191 Frame 0757.

6. ☒ Attached is the following number of Assignments (including original and all later successive ones by different assignors): 1 and respective **new** Cover Sheets. (Do **NOT** file old cover sheets.)

(Assignments in parent **must be refiled** with new Cover Sheets in this continuing application if you want it/them recorded against the continuing application.)

Please return the recorded Assignment to the undersigned.

7. ☒ The power of attorney in the prior application is to Pillsbury Madison & Sutro, L.L.P., including Peter W. Gowdey, Reg. No. 25872
(Name and Reg. No.)
whose current address is as in item 8 below.

a. ☒ Recognize as associate attorney Gary R. Tanigawa, Reg. No. 43180
(Name, Reg. No. and Address)

8. **Address all future communications to Intellectual Property Group of Pillsbury Madison & Sutro LLP, Ninth Floor, East Tower 1100 New York Avenue, N.W., Washington, D.C. 20005-3918**

9. ☒ **Amend the specification** by inserting before the first line the sentence:--This is a ☒ continuation ☐ division of Application No. 08/925,323, filed September 8, 1997
series code ⇧ ⇧ serial no.
.--

9. (a) ☐ **Amend the specification** by inserting before the first line: --This application claims the benefit of Provisional Application No. 60/___, filed ___ .--

10. ☐ It has been recently determined that this new continuing application is entitled to small entity status. Hence:
__(No.) Verified Statement(s) establishing "small entity" status under Rules 9 & 27 were/are:
☐ filed in above prior application (and hence applicable hereto)
☐ attached.

11. Petition to extend the life of the above prior application to at least the date hereof
(one box) ☐ is being concurrently filed in that prior application (Use Form PAT-111).
(must be) ☐ was previously filed in that prior application (Check length of prior extension).
(X'd) ☐ is not necessary for copendency (**Double check** before X'ing this box).

12. ☒ **INFORMATION DISCLOSURE STATEMENT:** Attached is Form PTO-1449 listing all of the documents cited by Applicant and the PTO in the parent application(s) relied upon under 35 USC 120 and referenced in item 9 above. Per Rule 98(d) copies of those documents are not required now. Please consider those documents and advise that they have been considered in this new application as by returning a copy of the enclosed Form PTO-1449 with the Examiner's initials in the left column per MPEP 609. .

13. ☐ Attached is a Rule 103(a) Petition to Suspend Action.

14. ☐ **PRELIMINARY AMENDMENT to be entered before fee calculation:** (Do not make amendments here except for correction of improper multiple dependencies or cancellation of whole claims or multiple dependencies for purpose of reducing the filing fee per MPEP §§ 506 and 607; do not cancel all claims).

FILING FEE

THE FOLLOWING FILING FEE IS BASED ON

->->->->CLAIMS AS FILED AND **CHANGED BY PRELIMINARY AMENDMENT IN ITEM 14**<-<-<-<-

NOTE: If box 1A2 is X'd, do not pay fees, but leave lines 15-22 and 27-32 blank.

PTO: PLEASE NOTE CLAIM CANCELLATIONS IF BOX 14 ABOVE IS X'D.

				Large/Small Entity		Fee Code
15. Basic Filing Fee .... Design Application				$320/$160		106/26
16. Basic Filing Fee .... Not Design Application				$710/$355	+710	101/201
17. Total Effective Claims	20	minus 20 =	0	x $18/$9	+0	103/203
18. Independent Claims	3	minus 3 =	0	x $80/$40	+0	102/202
19. If any proper multiple dependent claim (ignore improper) is present,				$270/$135	+0	104/204
20.				**Subtotal =**	**$710**	
21. If "petition" box 13 above is X'd, add petition fee. $130					+0	122
21A. If box 6 above is X'd, add Assignment recording fee .... $ 40					+40	581

22. **TOTAL FILING FEE ATTACHED = $750**

(carry forward to Item 31)

23. ☐ ATTACHED:

24. ☐ Preliminary Amendment attached (to be entered after assigning Appln. No.)

25. ☐ The following PRELIMINARY AMENDMENT is to be entered after assigning Appln. No.:

26. **ADDITIONAL FEE CALCULATION FOR PRELIMINARY AMENDMENT PER BOXES 24/25**

	Claims remaining after amendment		Highest number previously paid for		Present Extra		Large/Small Entity		Additional Fee	File Code
27. Total Effective Claims	*20	minus **	20	=	0	x	$18/$9	=	$ 0	(103/203)
28. Independent Claims	*3	minus ***	3	=	0	x	$78/$39	=	+ 0	(102/202)

29. If amendment enters proper multiple dependent claim(s) into this application for the first time, add (per application) ....$260/$130 + 0 (104/204)

30. ADDITIONAL FEE $ 0

31. plus **FEE** from item 22 on page 3 + 750

32. **TOTAL FEE ATTACHED** $ 750

33. *If the entry in this space is less than a entry in the next space, the "Present Extra" result is "0"

34. **If the "Highest number previously paid for" (see item 17 above) is less than 20, write "20" in this space

35. If the "Highest number previously paid for" (see item 18 above) is less than 3, write "3" in this space

Our Deposit Account No. 03-3975

Our Order No. 51273 (C#) | 268415 (M#)

CHARGE STATEMENT: Upon the filing of a Declaration pursuant to Rule 60(b) or 60(d), the Commissioner is hereby authorized to charge any fee specifically authorized hereafter, or any missing or insufficient fee(s) filed, or asserted to be filed, or which should have been filed herewith or concerning any paper filed hereafter, and which may be required under Rules 16-18 (missing or insufficient fee only) now or hereafter relative to this application and the resulting Official document under Rule 20, or credit any overpayment, to our Account/Order Nos. shown above for which purpose a duplicate copy of this sheet is attached.

This CHARGE STATEMENT does not authorize charge of the issue fee until/unless an issue fee transmittal form is filed.

Pillsbury Madison & Sutro LLP
Intellectual Property Group

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Ninth Floor
Washington, D.C. 20005-3918
Tel: (202) 861-3000

By Atty: Peter W. Gowdey **Reg. No.** 25872

Sig:

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PWG/GRT:nlh
Atty./Sec.

NOTE No. 1: File this Request in duplicate with 2 postcard receipts (PAT-103) & attachments
NOTE No. 2: Is extension in parent necessary for copendency? **DOUBLE CHECK** Item 11 above.
If yes, printout Pat-111 and head it in parent.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re PATENT Application of

KOIDE et al.

Continuation of Appln. No. 08/925,323 Group Art Unit: 2815

Filed: November 15, 2000 Examiner: J. Jackson

FOR: METHODS FOR MANUFACTURING A LIGHT-EMITTING DEVICE

* * *

November 15, 2000

PRELIMINARY AMENDMENT

Sir:

Prior to substantive examination, entry and consideration of the following amendments and remarks are respectfully requested.

IN THE TITLE:

Kindly replace all occurrences of the original title with --METHODS FOR MANUFACTURING A LIGHT-EMITTING DEVICE--.

IN THE SPECIFICATION:

Kindly amend the specification as follows.

Page 1, line 2, insert on separate lines

--CROSS-REFERENCE TO RELATED APPLICATIONS

This is a continuation of Application No. 08/925,323, filed September 8, 1997, now allowed.--.

line 19, delete "one-dot chain", before "line" insert --dashed--.

Page 2, line 8, delete "one-dot chain", after "the" insert --dashed--.

Page 3, line 5, after "people" insert --,--;

line 17, delete "one-dot chain", before "line" insert --dashed--; and

line 19, change "therefor" to --therefore--.

Page 6, line 16, after "layer" insert --11--; and

line 18, before "group" insert --a--.

IN THE CLAIMS:

Kindly cancel claims 1-20 and add the following new claims.

--21. A method of manufacturing a light-emitting device comprising forming a light-emitting layer comprised of $In_XGa_{1-X}N$, wherein the light-emitting layer has an indium mole fraction X and emits light of wavelength λ (nm) = 1239.8/Eg (eV), over a sapphire substrate; such that the emitted light has an energy level Eg < 3.4 * (1 – X) + 1.95 * X – 1.0 * X * (1 – X).

22. A method according to claim 21, wherein the emitted light has an energy level Eg approximately calculated in accordance with the following: Eg = 3.4 * (1 – X) + 1.95 * X – 4.26 * X * (1 – X).

23. A method according to claim 22, wherein the indium mole fraction X is set from about 0.13 to about 0.18 and the light-emitting layer emits light having a peak wavelength ranging from 460 nm to 480 nm.

24. A method according to claim 22, wherein the indium mole fraction X ranges from about 0.13 to about 0.18 and the light-emitting layer emits blue light.

25. A method according to claim 22, wherein the indium mole fraction X is set from about 0.20 to about 0.23 and the light-emitting layer emits light having a peak wavelength ranging from 510 nm to 530 nm.

26. A method according to claim 22, wherein the indium mole fraction X ranges from about 0.19 to about 0.26, and the light-emitting layer emits green light.

27. A method according to claim 21 further comprising:

disposing a buffer layer comprising AlN on the sapphire substrate;

interposing a first clad layer comprising n-GaN between the buffer layer and the light-emitting layer; and

forming a second clad layer comprising p-GaN doped with magnesium over the light-emitting layer.

28. A method according to claim 27 further comprising:

disposing a transparent electrode comprising gold on the second clad layer; and

disposing an electrode pad on the first clad layer.

29. A method according to claim 27 further comprising:

interposing a layer comprising $Al_XIn_YGa_{1-X-Y}$ (including X=0, Y=0, X=Y=0), wherein said interposed layer has a wide band gap and is doped with an acceptor, between the light-emitting layer and the second clad layer.

30. A method according to claim 29, wherein the acceptor is a group IIA element.

31. A method according to claim 29, wherein the acceptor is magnesium.

32. A method according to claim 27, wherein the layers are grown as crystals by a metal organic vapor phase epitaxial growth method with nitrogen, ammonia and alkyl compound gases containing a group III element.--

REMARKS

Claims 21-32 are pending.

The title has been amended to be descriptive of the claimed invention. A reference to a related application and a priority claim have also been added.

Moreover, the specification has been amended to include corrections requested by the Examiner in the parent application. In addition, a correction has been made to Figure 2, in accordance with the Examiner's request in the parent application that all claimed features be illustrated: a layer 11 that may be present is shown by a dotted line. Since this is optional, a dotted line rather than a full line has been used. The attached Figure 2 is a redlined version showing the correction. Support for this change in Figure 2 is found on page 6, lines 16-22, of the present specification. It is believed that this correction is supported by the original disclosure and, thus, no new matter has been added. Approval by the Examiner of this correction to Figure 2 is respectfully requested.

A prompt and complete examination on the merits is earnestly solicited. If further information is required, the Examiner is invited to contact the undersigned.

Respectfully submitted,

Cushman Darby & Cushman
Intellectual Property Group of
PILLSBURY MADISON & SUTRO, LLP

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APPLICATION UNDER UNITED STATES PATENT LAWS

Atty. Dkt. No. PMS 268415
(M#)

Invention: METHODS FOR MANUFACTURING A LIGHT-EMITTING DEVICE (as amended)

Inventor(s): KOIDE, Norikatsu
KOIKE, Masayoshi
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AKASAKI, Isamu
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This is a:

- ☐ Provisional Application
- ☐ Regular Utility Application
- ☒ Continuing Application
  - ☒ The contents of the parent are incorporated by reference
- ☐ PCT National Phase Application
- ☐ Design Application
- ☐ Reissue Application
- ☐ Plant Application
- ☐ Substitute Specification
  Sub. Spec Filed ______
  in App. No. ___/______
- ☐ Marked up Specification re
  Sub. Spec. filed ______
  In App. No ___/______

SPECIFICATION

SEMICONDUCTOR LIGHT-EMITTING DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a semiconductor light-emitting device. This semiconductor light-emitting device can be utilized as a light-emitting diode, a laser diode, or the like.

2. Description of the Conventional Art

Light-emitting devices using compound semiconductors cover visible short wavelength regions. Among other light-emitting diodes, nitride III semiconductors have attracted attention in recent years because these semiconductors are direct transition semiconductors, so that they exhibit high light-emitting efficiency, and because these semiconductors emit blue light, which is one of the three primary colors.

When the light-emitting layer is formed of $In_XGa_{1-X}N$, it has heretofore been considered that a relation such as shown by the one-dot chain line in Fig. 1 exists between the indium mole fraction X and the photon energy (see "Journal of applied physics", Vol. 46, No. 8, August 1975, pp. 3432-3437 and "Microelectronics Journal", 25 (1994), pp. 651-659). The photon energy of the wavelength λ of blue light (470 nm) is almost 2.64 eV, and the photon energy of the wavelength λ of green light (520 nm) is almost 2.38 eV. Therefore, according

to the conventionally proposed relation, blue emission is obtained by setting the indium mole fraction X to approximately 0.26 and green emission is obtained by setting the indium mole fraction X to approximately 0.67 if no impurities are to be added.

As a result of a continued study on the light-emitting layer formed of $In_XGa_{1-X}N$, the inventors realized that the conventionally proposed relationship shown by the one-dot chain line in Fig. 1 could not be applied without modification if such a light-emitting layer is to be formed on a sapphire substrate.

SUMMARY OF THE INVENTION

To overcome the aforementioned problem, the inventors further studied the relationship between the indium mole fraction X and the photon energy in a light-emitting layer formed of $In_XGa_{1-X}N$ on a sapphire substrate. As a result, a relationship shown by the solid line in Fig. 1 was found. When converted into a relationship between a wavelength λ and the indium mole fraction X, this relationship can be given as follows.

(1) $\lambda\ (nm) = 1239.8/Eg\ (eV)$

(2) $Eg = 3.4 * (1-X) + 1.95 * X - 4.26 * X * (1-X)$

According to the above equations (1) and (2), a ray of light having a peak wavelength ranging from 460 to 480 nm is

emitted when the indium mole fraction X is set to 0.14 to 0.16. As a result, when the indium mole fraction X in a light-emitting layer formed of $In_XGa_{1-X}N$ on a sapphire substrate was set to 0.13 to 0.18, it was found that blue light, i.e., blue light as visually observed by people was emitted from such a light-emitting layer.

Further, according to the above equations (1) and (2), a ray of light having a peak wavelength ranging from 510 to 530 nm is emitted when the indium mole fraction X is set to 0.20 to 0.23. As a result, when the indium mole fraction X in a light-emitting layer formed of $In_XGa_{1-X}N$ on a sapphire substrate was set to 0.19 to 0.26, it was found that green light, i.e., green light as visually observed by people, was emitted from such light-emitting layer.

The solid line in Fig. 1 that shows the newly discovered relationship is characterized by a line more sharply inclined than the one-dot chain line in Fig. 1, which shows the conventionally proposed relationship. A conceivable reason therefor is that since the lattice constant of a semiconductor constituting the light-emitting layer is different from that of the sapphire substrate, the light-emitting layer is distorted, and as a result, the photon energy is decreased, i.e., the wavelength is shifted toward long wavelengths even if the indium mole fractions are the same.

The relationships shown in Fig. 1 illustrate cases

where light-emitting layers are formed of $In_XGa_{1-X}N$ with no intentional impurities contained.

Of course, impurities can be doped into a compound semiconductor constituting a light-emitting layer. When impurities are doped into a light-emitting layer, the wavelength is shifted toward long wavelengths even if the indium mole fraction is the same. On the other hand, if the light-emitting layer contains a quantum well layer, the wavelength is shifted toward short wavelengths due to quantum effects.

It may be noted that the data shown by the solid line in Fig. 1 were obtained as follows.

A 2 μm-thick GaN layer was formed on a surface a of a disc-like 100 μm-thick sapphire substrate by means of a metal organic vapor phase epitaxial growth method (hereinafter abbreviated as the "MOVPE method"), and a 20 nm-thick $In_XGa_{1-X}N$ layer was formed thereon similarly by means of the MOVPE method.

A pulse laser was irradiated (at an excitation strength of 200 kW/cm^2) onto the $In_XGa_{1-X}N$ layer at room temperature. Then, the wavelength λ of a ray of light emitted from the $In_XGa_{1-X}N$ layer was measured. The photon energy Eg was calculated from the peak wavelength λ of such ray of light. It may be noted that such a relationship as $\lambda = 1239.8/Eg$ is established between the wavelength λ and the photon energy Eg

(eV).

The indium mole fraction was calculated by means of an AES (Auger electron spectroscopy) method.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

Fig. 1 is a graph showing relationships between the indium mole fraction and photon energy of rays of light emitted from light-emitting layers; and

Fig. 2 is a sectional view of a light-emitting diode, which is an embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The modes of embodiment of the invention will now be described further in detail with reference to specific examples.

1st Embodiment

A semiconductor light-emitting device according to the first embodiment is a blue light-emitting diode having a peak wavelength of 470 nm. Fig. 2 is a sectional view of a light-emitting diode 10 according to this embodiment.

This light-emitting diode 10 is formed by having a buffer layer 2 comprising AlN, a first clad layer 3 comprising n-GaN, a light-emitting layer 4 made of InGaN, and a second clad layer 5 made of p-GaN doped with magnesium grown

sequentially on a sapphire substrate 1. A transparent electrode 6 made of gold is further arranged on the upper surface of the second clad layer 5, and an electrode 8 is deposited further on the transparent electrode 6 by vacuum evaporation. An electrode pad 7 is arranged also on the first clad layer 3.

The first clad layer 3 is formed on the sapphire substrate 1 through the buffer layer 2 made of AlN. The first clad layer 3 may be of a double-layered structure with an n-layer having a low electron density on the light-emitting layer side and an n^- layer having a high electron density on the buffer layer side.

The light-emitting layer 4 is not limited to a double heterostructure shown in Fig. 2, but may be applied to a single heterostructure, a superlattice structure, and the like.

An $Al_XIn_YGa_{1-X-Y}N$ (including X=0, Y=0, X=Y=0) layer, which has a wide band gap and which is doped with an acceptor such as group IIA element, preferably magnesium, may be interposed between the light-emitting layer 4 and the p-type second clad layer 5. This technique is employed for preventing electrons implanted into the light-emitting layer 4 from being diffused into the second clad layer 5.

The second layer 5 may be of a double structure with a p-layer having a low magnesium density on the light-emitting side and a p-layer having a high magnesium density on the

electrode side.

The magnesium-doped p-type second clad layer 5 has a large resistance. Therefore, even if a current is introduced only from the electrode 8 to one end of the second clad layer 5, it is likely that current density will not become uniform over the entire area of the light-emitting layer 4. To overcome this problem, the thin-filmed transparent electrode 6 that extends over substantially the entire area of the second clad layer 5 is interposed between the electrode 8 and the second clad layer 5.

As a material of which the electrode 8 and the transparent electrode 6 is made includes: Au, Pt, Pd, Ni, or an alloy containing these metals. These metals and alloys are formed on the second clad layer 5 by vacuum evaporation.

The electrode 7 that is connected to the n-type first clad layer 3 is made of Al, Ti, or an alloy containing these metals.

A method of preparing the light-emitting diode 10 according to the first embodiment and specifications of the respective layers will be described next.

The respective semiconductor layers of the light-emitting diode are formed by means of the MOVPE method. In this growth method, a desired crystal is grown on a substrate by supplying ammonia and alkyl compound gases containing group III elements such as trimethylgallium (TMG), trimethylaluminum

(TMA), and trimethylindium (TMI) to a substrate that has been heated to an appropriate temperature and by subjecting the gases to a thermal decomposition process.

A single-crystal sapphire substrate 1, having a surface cleaned by an organic cleaning process and a thermal treatment, is attached as a main surface to the susceptor within a vapor-phase reaction system. Then, the sapphire substrate is subjected to a vapor phase etching process at 1100°C while introducing N_2 into the reaction system at a flow rate of 2 l/min at atmospheric pressure.

Then, the buffer layer 2, made of AlN, is formed on the substrate to a thickness of about 50 nm by decreasing the temperature to 400°C and by supplying N_2 at a flow rate of 20 l/min, NH_3 at a flow rate of 10 l/min, and TMA at a flow rate of 1.8×10^{-5} mol/min.

Then, the first clad layer 3, made of silicon-doped GaN and having a film thickness of about 2200 nm and an electron density of $2 \times 10^{18}/cm^3$, is formed by keeping the temperature of the sapphire substrate and the buffer layer at 1150°C and by introducing TMG at a flow rate of 1.12×10^{-4} mol/min and NH_3 at a flow rate of 10 l/min.

Then, the light-emitting layer 4, made of $In_{0.15}Ga_{0.85}N$ and having a film thickness of about 500 nm, is formed by keeping the temperature at 850°C and by introducing N_2 at a flow rate of 20 l/min, NH_3 at a flow rate of 10 l/min, TMG at

a flow rate of 1.53 x 10^{-4} mol/min, and TMI at a flow rate of 0.02 x 10^{-4} mol/min.

Then, the second clad layer 5, made of magnesium-doped GaN and having a film thickness of about 1000 nm, is formed by keeping the temperature at 850°C and by introducing N_2 at a flow rate of 20 l/min, NH_3 at a flow rate of 10 l/min, TMG at a flow rate of 1.12 x 10^{-4} mol/min, and CP_2Mg at a flow rate of 2 x 10^{-4} mol/min. The concentration of magnesium in the second clad layer 5 is 1 x $10^{20}/cm^3$. The second clad layer 5 is a high-resistance semi-insulator.

Electron beams are thereafter irradiated uniformly onto the second clad layer 5 using an electron beam irradiation system. The electron beam irradiating conditions are: an acceleration voltage of about 10 kV, a sample current of 1 μA, a beam moving velocity of 0.2 mm/sec, a beam diameter of 60 μm, and a vacuum degree of 5.0 x 10^{-5} Torr. The second clad layer 5 is transformed into a desired p-type layer while subjected to an electron beam irradiation process performed under the above conditions. It may be noted that the resistance of the second clad layer 5 ranges from 30 to 70 Ω/cm.

The thus formed semiconductor wafer is subjected to a known etching process to have such semiconductor layer structure as shown in Fig. 2. Successively, the electrode 7 is formed on the first clad layer 3 by vacuum evaporation; the transparent electrode 6 made of gold is deposited on the second

clad layer 5; and the electrode 8 made of gold is further arranged on the transparent electrode 6 by vacuum evaporation.

The thus formed semiconductor wafer is cut into unit elements to form desired blue light-emitting diodes.

When a forward current of 3.5 V and 20 mA is applied, a blue light-emitting diode emits blue light as visually observed. When this blue light is subjected to a spectroscopic analysis, the peak wavelength thereof is 470 nm.

<u>2nd Embodiment</u>

A light-emitting diode in the second embodiment is a green light-emitting diode having a peak wavelength of 520 nm.

The light-emitting diode according to this embodiment is characterized in that the light-emitting layer comprises $In_{0.21}Ga_{0.79}N$. The light-emitting layer is formed similarly to that of the first embodiment while adjusting the flow rate of TMI.

The specifications of other layers in the second embodiment are the same as those in the first embodiment.

When a forward current of 3.5 V and 20 mA is applied, a green light-emitting diode emits green light as visually observed. When this green light is subjected to a spectroscopic analysis, the peak wavelength thereof is 520 nm.

The invention is not limited to the aforementioned descriptions of the modes of embodiment and specific examples thereof whatsoever, and includes various modifications that can

be conceived by the skilled in the art without departing from the scope of the claims.

The invention is, of course, applicable to laser diodes.

As described in the foregoing, a light-emitting layer that is formed on a sapphire substrate and that is made of $In_XGa_{1-X}N$ exhibits the following approximate relationship between the indium mole fraction X and the wavelength λ of an emitted ray of light, this relationship being a new discovery.

$$\lambda\ (nm) = 1239.8/Eg\ (eV)$$

$$Eg = 3.4 * (1-X) + 1.95 * X - 4.26 * X * (1-X)$$

On the other hand, in the conventionally proposed relationship, the coefficient in the third term was -1.0 as shown in Fig. 1.

Therefore, according to the invention, the indium mole fraction X is smaller than in the convention example when a ray of light having the same wavelength is to be emitted. For example, to emit rays of light whose wavelengths are 470 nm and 520 nm, indium mole fractions of 0.26 and 0.67 were required in the conventional example, while indium mole fractions of 0.15 and 0.21 are required according to the present invention. It is generally said that a larger indium mole fraction impairs the crystal quality of a light-emitting layer and thus reduces light-emitting efficiency. Hence, according to the invention, a semiconductor light-emitting device having a light-emitting

layer whose light-emitting efficiency is high can be provided.

Further, the following method for controlling a wavelength of a semiconductor light-emitting device can be obtained based on the aforementioned facts. That is, in a semiconductor light-emitting device having a sapphire substrate with a light-emitting layer being formed of $In_XGa_{1-X}N$ and emitting light whose wavelength is λ, the wavelength λ is controlled while changing the indium mole fraction X so as to satisfy the following relationship:

$$\lambda\ (\mathrm{nm}) = 1239.8/Eg\ (\mathrm{eV})$$

$$Eg = 3.4 * (1-X) + 1.95 * X - 4.26 * X * (1-X).$$

WHAT IS CLAIMED IS:

1. A light-emitting device comprising:

a sapphire substrate; and

a light-emitting layer comprising $In_XGa_{1-X}N$, wherein said light-emitting layer has an indium mole fraction X ranging from about 0.13 to about 0.18 and emits blue light.

2. A light-emitting device according to claim 1, further comprising:

a buffer layer comprising AlN;

a first clad layer comprising n-GaN; and

a second clad layer comprising p-GaN doped with magnesium.

3. A light-emitting device according to claim 2, further comprising:

a transparent electrode comprising gold disposed on said second clad layer; and

an electrode pad disposed on said first clad layer.

4. A light-emitting device according to claim 2, further comprising:

an interposed layer comprising $Al_XIn_YGa_{1-X-Y}N$, wherein said interposed layer has a wide band gap, is doped

with an acceptor, and is interposed between said light-emitting layer and said second clad layer.

5. A light-emitting device according to claim 4, wherein said acceptor is a group IIA element.

6. A light-emitting device according to claim 4, wherein said acceptor is magnesium.

7. A light-emitting device comprising:

a sapphire substrate; and

a light-emitting layer comprising $In_XGa_{1-X}N$, wherein said light emitting layer has an indium mole fraction X ranging from about 0.19 to about 0.26 and emits green light.

8. A light-emitting device according to claim 7, further comprising:

a buffer layer comprising AlN;

a first clad layer comprising n-GaN; and

a second clad layer comprising p-GaN doped with magnesium.

9. A light-emitting device according to claim 8, further comprising:

a transparent electrode comprising gold disposed

on said second clad layer; and

an electrode pad disposed on said first clad layer.

10. A light-emitting device according to claim 8, further comprising:

an interposed layer comprising $Al_XIn_YGa_{1-X-Y}N$, wherein said interposed layer has a wide band gap, is doped with an acceptor, and is interposed between said light-emitting layer and said second clad layer.

11. A light-emitting device according to claim 10, wherein said acceptor is a group IIA element.

12. A light-emitting device according to claim 10, wherein said acceptor is magnesium.

13. A semiconductor light-emitting device comprising:

a sapphire substrate; and

a light-emitting layer comprising $In_XGa_{1-X}N$ with an indium mole fraction X and emitting light with a wavelength λ;

wherein the indium mole fraction X and the wavelength λ of the emitted light approximately satisfy the following conditions:

$$\lambda \text{ (nm)} = 1239.8/Eg \text{ (eV)}$$

$$Eg = 3.4 * (1-X) + 1.95 * X - 4.26 * X * (1-X).$$

14. A semiconductor light-emitting device according to claim 13, wherein the indium mole fraction X ranges from about 0.13 to about 0.18, and the light-emitting layer emits blue light.

15. A semiconductor light-emitting device according to claim 13, wherein the indium mole fraction X ranges from about 0.19 to about 0.26, and the light-emitting layer emits green light.

16. A semiconductor light-emitting device according to claim 13, further comprising:

a buffer layer comprising AlN;

a first clad layer comprising n-GaN; and

a second clad layer comprising p-GaN doped with magnesium.

17. A semiconductor light-emitting device according to claim 16, further comprising:

a transparent electrode comprising gold disposed on said second clad layer; and

an electrode pad disposed on said first clad

layer.

18. A semiconductor light-emitting device according to claim 16, further comprising:

an interposed layer comprising $Al_XIn_YGa_{1-X-Y}N$, wherein said interposed layer has a wide band gap, is doped with an acceptor, and is interposed between said light-emitting layer and said second clad layer.

19. A light-emitting device according to claim 18, wherein said acceptor is a group IIA element.

20. A light-emitting device according to claim 18, wherein said acceptor is magnesium.

ABSTRACT OF THE DISCLOSURE

A novel light-emitting device includes a saphire substrate with a light-emitting layer comprising $In_XGa_{1-X}N$, where the critical value of the indium mole fraction X is determined by a newly derived relationship between the indium mole fraction X and the wavelength λ of emitted light.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re PATENT Application of

KOIDE et al.

Continuation of Appln. No. 08/925,323 Group Art Unit: 2815

Filed: November 15, 2000 Examiner: J. Jackson

FOR: METHODS FOR MANUFACTURING A LIGHT-EMITTING DEVICE

* * *

November 15, 2000

<u>DRAWING CHANGE AUTHORIZATION REQUEST</u>

Sir:

The Examiner's approval of the drawing change shown in red on the attached FIGURE 2 is respectfully requested. If further information is required, the Examiner is invited to contact the undersigned.

Respectfully submitted,

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Fig. 2

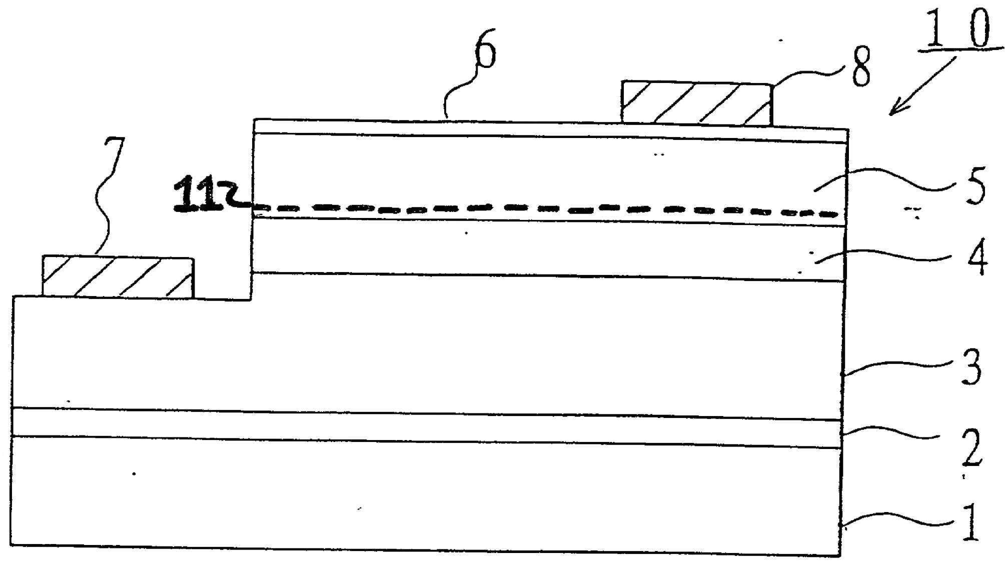
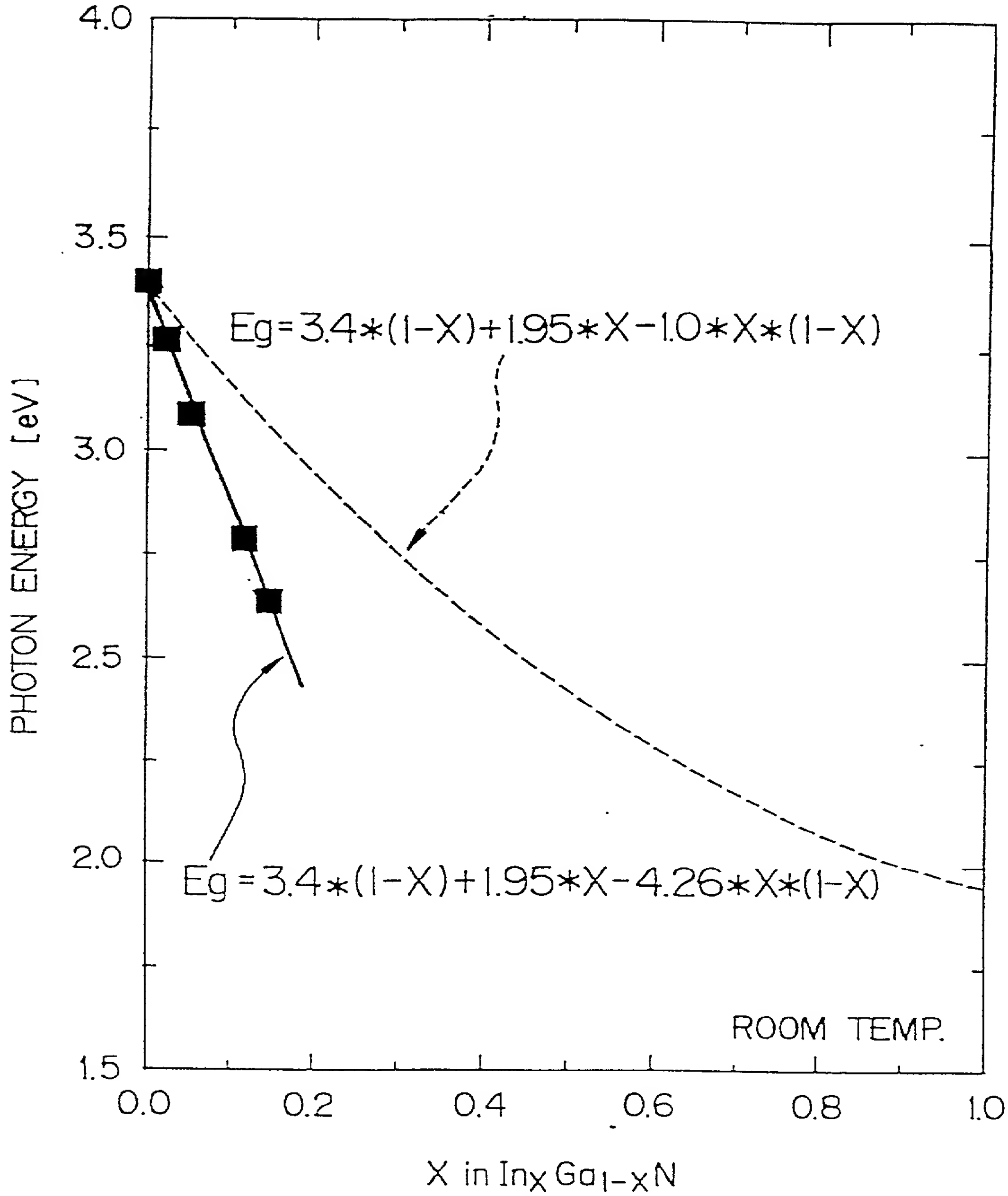
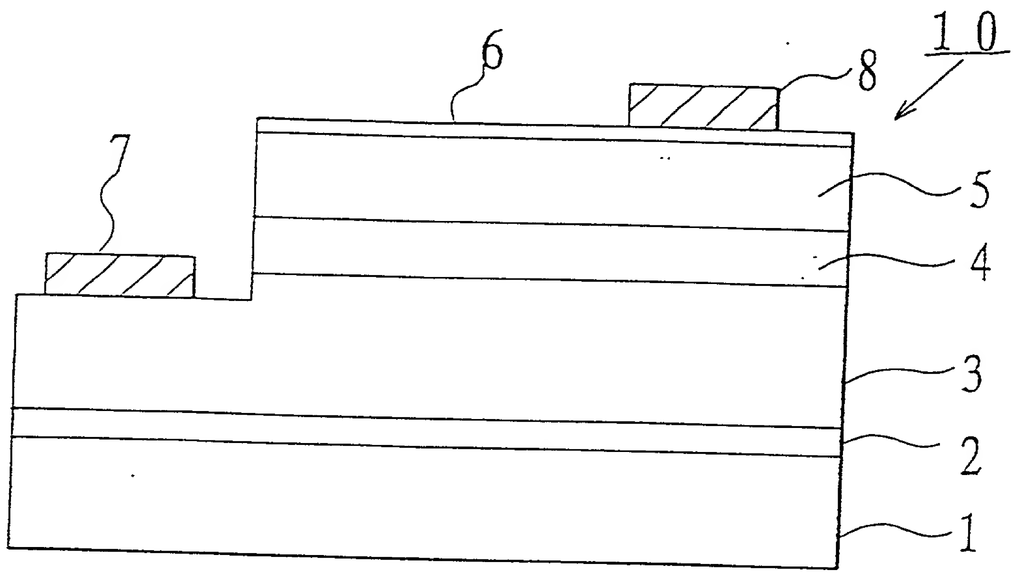


Fig. 1



4.0
3.5
3.0
2.5
2.0
1.5
PHOTON ENERGY [eV]
Eg=3.4*(1-X)+1.95*X-1.0*X*(1-X)
Eg=3.4*(1-X)+1.95*X-4.26*X*(1-X)
ROOM TEMP.
0.0
0.2
0.4
0.6
0.8
1.0
X in InX Ga1-X N

Fig. 2



FOR UTILITY/DESIGN
CIP/PCT NATIONAL/PLANT
ORIGINAL/SUBSTITUTE/SUPPLEMENTAL
DECLARATIONS

RULE 63 (37 C.F.R. 1.63)
DECLARATION AND POWER OF ATTORNEY
FOR PATENT APPLICATION
IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

CUSHMAN
FORM

As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name, and I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the INVENTION ENTITLED
SEMICONDUCTOR LIGHT-EMITTING DEVICE

the specification of which (CHECK applicable BOX(ES))
-> [ ] is attached hereto.
X -> [X] was filed on September 8, 1997 as U.S. Application No. 08/ 925,323
BOX(ES) -> [ ] was filed as PCT International Application No. PCT/ / on
->-> and (if applicable to U.S. or PCT application) was amended on

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose all information known to me to be material to patentability as defined in 37 C.F.R. 1.56. I hereby claim foreign priority benefits under 35 U.S.C. 119/365 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate filed by me or my assignee disclosing the subject matter claimed in this application and having a filing date (1) before that of the application on which priority is claimed, or (2) if no priority claimed, before the filing date of this application:

PRIOR FOREIGN APPLICATION(S) Number	Country	Day/MONTH/Year Filed	Date first Laid-open or Published	Date Patented or Granted	Priority Claimed Yes	No
Pat. Hei. 8-257818	Japan	08/09/1996			X	

I hereby claim domestic priority benefit under 35 U.S.C. 120/365 of the indicated United States applications listed below and PCT international applications listed above or below and, if this is a continuation-in-part (CIP) application, insofar as the subject matter disclosed and claimed in this application is in addition to that disclosed in such prior applications, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in 37 C.F.R. 1.56 which became available between the filing date of each such prior application and the national or PCT international filing date of this application:

PRIOR U.S. PROVISIONAL, NONPROVISIONAL AND/OR PCT APPLICATION(S) Application No. (series code/serial no.)	Day/MONTH/Year Filed	Status pending, abandoned, patented	Priority Claimed Yes	No

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

And I hereby appoint Cushman Darby & Cushman Intellectual Property Group of Pillsbury Madison & Sutro LLP, 1100 New York Avenue, N.W., Ninth Floor, East Tower, Washington, D.C. 20005-3918, telephone number (202) 861-3000 (to whom all communications are to be directed), and the below-named persons (of the same address) individually and collectively my attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith and with the resulting patent, and I hereby authorize them to delete names/numbers below of persons no longer with their firm and to act and rely on instructions from and communicate directly with the person/assignee/attorney/firm/organization who/which first sends/sent this case to them and by whom/which I hereby declare that I have consented after full disclosure to be represented unless/until I instruct the above Firm and/or a below attorney in writing to the contrary.

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DECLARATION AND POWER OF ATTORNEY
(continued)

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Post Office Address (Include Zip Code)

FOR ADDITIONAL INVENTORS, check box ☐ and attach sheet with same information and signature and date for each.